MINISTRY OF ENERGY AND MINERAL RESOURCES REPUBLIC OF INDONESIA

GEOLOGICAL AGENCY

JALAN DIPONEGORO NO. 57 BANDUNG 40122
JALAN JEND. GATOT SUBROTO KAV. 49 JAKARTA 12950

Telephone: 022-7215297, 021-5228371 Facsimile: 022-7216444, 021-5228372 e-mail: geologi@bgl.esdm.go.id

GUIDELINES FOR REVIEWERS

General:

- Please comment objectively to provide the author(s) with the means to improve their paper. Feel free to make extended comments on separate sheets.
- If a paper repeats previously published work please point this out to the editor.
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- Some questions below should be answered on a scale of A to D, **where A is the highest rank and D is the lowest.**

Manuscript:
A hydrogeological model of an urban city in the coastal area, Case study : Semarang (Indonesia)

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1. Is this topic A. Suitable for the journal? **yes no** yes
B. Of broad national interest? **yes no** yes
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Please explain your answers to item 1A – C briefly.
Coastal area dominates the big cities in Indonesia, so that knowledge on groundwater in coastal area is important for the country.

2. Clarity of objectives: **A B C D** A

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6. Is this paper A. Properly organized? **yes no** No
B. To the point and concise? **yes no** yes
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Sequence of description of the results is improperly arranged. Not only the grammar, the vocabulary is also incorrect, that leads to confusion.

7. Are the approach, results and conclusions intelligible from the abstract? **yes no** yes

8. Is the title informative and a reflection of the content? **yes no** yes
However, the word "the" should not be in the title.

9. Are the illustrations/tables A. Useful and all necessary? yes no ...yes......
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Some figures cannot be read because the size of the letters is too small. There is no legend in Figure 2.

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12. Can you suggest any improvements to the paper or any parts that could be shortened or removed? [use separate sheet of paper if necessary to answer this]
a. Use correct vocabulary to convey the message
b. Result should be discussed with HSU first.
c. There is no basis at all to try to explain the mechanisms involved in formation of the groundwater chemistry.
Without this attempt, the manuscript should be acceptable.
d. Hydrochemistry should not be used for hydrostratigraphy.
e. I have written my complete comments in the manuscript.

13. Is this manuscript acceptable in its present form for publications? yes no ......No.........

14. Would this work be acceptable after: A. Minor revision? ....
B. Moderate revision? Moderate revision
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The Editors thank you for your efforts and cooperation in reviewing this manuscript.

Date: August 6, 2015

A hydrogeological model of an urban city in coastal area, Case study: Semarang (Indonesia)

Abstract In Semarang, Indonesia, groundwater has been exploited as a natural resource since 1841. Groundwater exploitation via deep wells is concentrated on a confined aquifer. The existing hydrogeological models were developed into one unit aquifer and refined then by using several hydrostratigraphical units following the regional hydrogeological map without any further analysis. A~~s~~t present, there is a lack of precise hydrogeological model, in particular, regarding the multiple aquifers in Semarang, which integrates geological and hydrogeological data. Thus, the aim of this paper is focused on developing a hydrogeological model of multiple aquifers in Semarang using an integrated data approach. Groundwater samples in the confined aquifer have been analysed to define water type and its lateral distribution. Two hydrogeological cross sections were then created based on several borelog data to define hydrostratigraphical unit (HSU). HSU of Semarang consists of two aquifers, three aquitards and an aquiclude. Aquifer 1 is unconfined while aquifer 2 is confined. Aquifer 2 is classified into three groups (2a, 2b and 2c) based on analyses of major ion content and hydrostratigraphical cross sections.

Keywords: hydrogeological model, hydrochemistry, hydrostratigraphical unit, aquifer, Semarang

Introduction

Semarang is one of the biggest cities in Indonesia and also ~~a~~ the capital city of Central Java Province, which is located in the northern coast of Java Island. The study area covers approximately 1,070 km^2 including Semarang urban area and Demak suburbs with the total population of up to 3 million inhabitants. It is located on 419500 to 480250 m in East Longitude and 9212850 to 9258190 m in South Latitude using the Universal Transverse Mercator (UTM) zone 49 South (Fig. 1). In Semarang, groundwater has been exploited as a natural resource since the first deep well was drilled at Fort Wilhelm I in 1841 (Dahrin et al., 2007). Since then, the numbers of registered deep wells have increased sharply: in 1900 the total number of deep wells were 16 wells, whereas 260 were built in 1990's and 1,194 wells constructed in the first decade of 2000 with total groundwater withdrawal of around 45 MCM yr^{-1} (Directorate of Environmental Geology/DGTL, 2003). Groundwater exploitation via deep wells concentrate on a confined aquifer system.

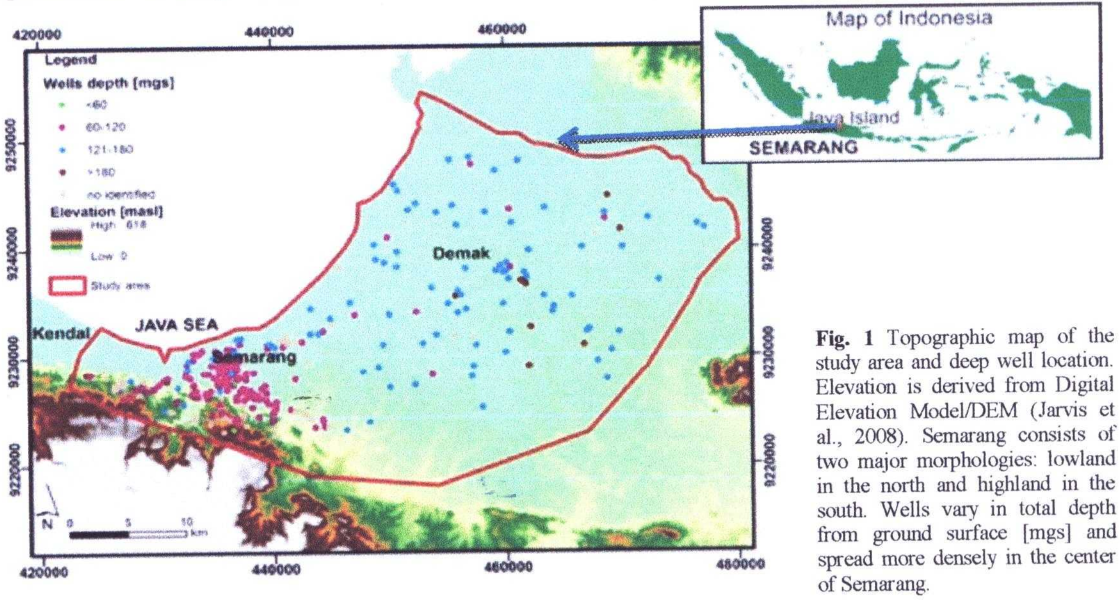

Fig. 1 Topographic map of the study area and deep well location. Elevation is derived from Digital Elevation Model/DEM (Jarvis et al., 2008). Semarang consists of two major morphologies: lowland in the north and highland in the south. Wells vary in total depth from ground surface [mgs] and spread more densely in the center of Semarang.

too long.

Spitz (1989) proposed the first hydrogeological model in Semarang urban area. The hydrogeological model was simplified into one deep confined aquifer system. Due to complex aquifers system, the result of first hydrogeological model conducted many lost interpretations not clear of hydrostratigraphy units (HSU). Haryadi et al (1991) improved a hydrogeological model for the regional coastal plain of Semarang. To develop a hydrogeological model, nine HSU were constructed. All units were illustrated as confined aquifers without any aquitard as a confined unit in the model. The lateral distribution was derived from the regional hydrogeological map without any further analy~~zing.~~sis

At present, there is a lack of precise hydrogeological model, in particular, regarding a multiple aquifer system in Semarang. Thus, this current paper is focused on developing a hydrogeological model of the Semarang multilayer aquifers by using an integration of geological and hydrogeological data. Firstly, the paper describes geological and hydrogeological setting, and then hydrogeochemical analysis is presented to define the water type and lateral distribution. Lastly, the development of HSU was constructed by interpretation of two hydrogeological cross sections from several borelogs.

Geological and Hydrogeological Setting

Similar with other regions in Indonesia, Semarang has a tropical climate with two distinct seasons: monsoon wet and dry. The rainy season (from November to April) has monthly rainfall around more than 150 mm mo^{-1} as the impact of west monsoon winds that blow~~s~~ from Asia towards Australia and bring abundant moisture from Java Sea and Indian Ocean. Meanwhile, the east monsoon (starts from May to October) brings much drier air from Australia. In this period, Indonesia will experience a dry season, so that minimum monthly rainfall in July and August is below 50 mm mo^{-1}. Meteorology, Climatology and Geophysics agency (BMKG) in Semarang estimated the weighted average of monthly rainfall and temperature using data from 1998 to 2007 as 174 mm mo^{-1} and 27.6°C, respectively (BMKG 2008).

should be on p. 4

Regionally, stratigraphy of Semarang is subdivided into three main groups that are surficial deposit and sedimentary rocks, volcanic rocks, and intrusive rocks (Fig. 2). Based on the regional geological maps of Semarang (Thanden et al. 1996), Salatiga (Sukardi and Budhitrisna 1992) and Kudus (Suwarti and Wikarno 1992), intrusive andesite (Tma) is the oldest rocks (middle Miocene age). Sedimentary rocks from old to young are Kerek Formation (Tmk) in the south and Wonocolo Formation (Tmw) in the east, Kalibeng Formation (Tmpk) containing Kapung (Tmkk), Damar (Tmkd) and Banyak (Tmkb) as members, Kaligetas Formation (Qpkg), and Damar Formation (QTd). Volcanic rocks (Ov u,m) are undifferentiated Ungaran Mt. and Muria Mt. products which are located in the south and in the north east, respectively. They consist of breccia, lava, tuff and laharic breccia. The youngest lithology is alluvium (Qa) as a result of coastal plain, river and lake processes.

Thanden et al. (1996) stated that Kerek (middle Miocene age) Formation consists of alternation of claystone, marl and limestone. The ~~C~~claystones are partly interlayered with siltstone or sandstone, while locally they contain forams, molluscs, and coral colonies. The ~~L~~imestones are commonly bedded and sandy with total thickness of more than 400 m. While Kalibeng (late Miocene-Pliocene) Formation consists of massive marl in the upper part, locally carbonaceous, ~~marls~~ intercalating with tuffaceous sandstone and limestone.

~~The~~ Damar Formation consists of tuffaceous sandstone, conglomerate, and volcanic breccia. The latter of which occurs as lahar deposits in the centre of Semarang area. Damar Formation is partly nonmarine, containing molluscs and vertebrate remains. Kaligetas Formation consists of breccia, lava flows, tuffaceous sandstone and claystone.

Mathon (1975) stated that the coastal plain of Semarang is formed by basin sediments deposited in a marine environment. The bulk of the basin sediments contain alluvium. It consists of thick layers of calcareous and shell bearing clay with thin intercalations of sand, and occasionally gravel to pebble or cemented gravel.

Tectonic activities were started at Early Tertiary by basaltic and andesitic intrusions, in the southern part of Semarang, and then continued by uplifting and erosion. The erosion ? conducted the turbidites of ~~the~~ Kerek Formation in neritic environment. It ~~is~~ was afterward succeeded by ~~the~~ Kalibeng Formation in ~~a~~ bathyal environment and basin filling of ~~the~~ Damar Formation in ~~a~~ transitional to ~~the~~ terrestrial environment. In Plio-Pleistocene age, tectonic activities reactivated the result of Early Tertiary deformation, and they form dominantly faults as shown in the south in Fig. 2. The young Quaternary volcanic rocks rise via the weak zones from fractures (Thanden et al. 1996).

Groundwater flows from the mountainous area in the south towards the coastal plain in the north. Groundwater flows predominantly in an intergranular system which consists of sedimentary deposits while volcanic rocks form an aquifer system of minor importance. They are fissure, interstice and fracture aquifer systems (Said and Sukrisno 1984).

Several hydrogeologic researchers stated that there are two aquifer systems in Semarang: an unconfined aquifer and a confined one (Said 1974; Sihwanto et al. 1988; Arifin and Mulyana 1990; Mulyana and Wahid 1994; Spitz and Moreno 1996; Arifin and Wahyudin 2000). The unconfined aquifer is formed by alluvial deposits consisting of intercalating sand

and clayey sand. Groundwater is abstracted by numerous dug wells, mainly for domestic water supply. The depth of the groundwater table ranges from 0.1 to 21.8 m below ground surface with increasing depth towards the hilly areas in the south (Susana and Harnandi 2007). Fluctuation occurs depending on the season: high and low in the rainy and dry seasons, respectively.

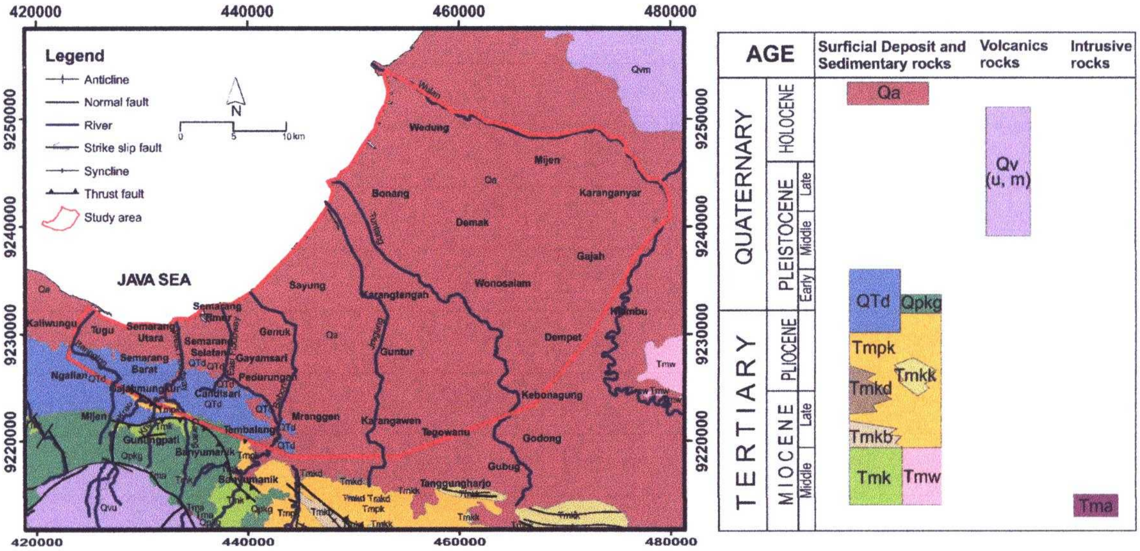

Fig. 2 Regional geological map (left) and stratigraphy (right) of Semarang (Thanden et al. 1996; Sukardi and Budhitrisna 1992; Suwarti and Wikarno 1992). Note: Qa (Alluvium); Qv (u,m) Volcanic rocks, undifferentiated Ungaran and Muria Mt.; QTd (Damar Formation); Qpkg (Kaligetas Formation); Tmpk (Kalibeng Formation); Tmkd (Damar members); Tmkk (Kapung members); Tmkb (Banyak members); Tmk (Kerek Formation); Tmw (Wonocolo Formation); Tma (Intrusive andesite).

Marine and volcanic sediments in the coastal and hilly areas ~~are~~ dominantly form the confined aquifer, respectively. Multiple layers that are separated by clay layers as aquitards set up the confined aquifer. The confined aquifer comprises of three groups, which are Quaternary marine, Garang, and Damar. Quaternary marine and Garang show quite similar ~~in~~ lithologic characteristic. They can only be distinguished by hydrogeochemical aspects. → source?

Moreover, Garang aquifer contains fresh water whereas Quaternary marine aquifer shows brackish or salty water. Damar aquifer is dominated by volcanic sedimentary rocks.

Materials & methods

The first step in developing a hydrogeological model is the definition of the geological and hydrogeological framework of the study area to ensure the natural system (Anderson and Woessner 1992; Spitz and Moreno 1996; Sefelnasr 2007; Singhal and Goyal 2011).

Many sources of hydrogeological and geological data contributed to the construction of the hydrogeological model. Data were obtained from hydrogeochemi~~stry~~ cal analysis of

?
groundwater samples, while well log and boring were collected to construct the hydrogeological cross section.

In the hydrogeochemis~~try~~cal analysis, major cation and anion contents were analysed to describe the water types and lateral distribution of the aquifers in the study area. The correctness of the chemical analysis was verified by calculating the ion balance error (IBE) using the following formula (Hötlz and Witthüser 1999):

$$IBE[\%] = \frac{\sum Cations - \sum Anions}{0.5 \times [\sum Cations + \sum Anions]} x100 \qquad \text{(Eq. 1)}$$

Furthermore, the regional geological (Fig. 2; scale 1:100,000) and the hydrogeological (Said and Sukrisno 1998; scale 1:250,000) maps of Semarang were used to understand geological and hydrogeological setting in the study area as well.

Two hydrostratigraphical cross sections were made to describe the subsurface conditions based on borelog data. Hydrostratigrapical units (HSU) concept was applied to define hydrogeologic conditions in the study area. The term HSU was first proposed by Maxey (1964) to describe bodies of rock with considerable lateral extent that compose a geological framework for reasonably distinct hydrological system. The systematic analysis using integration of geology, hydraulic head, and hydrochemistry data sets were used to define and verify the HSU.

Results & Discussion

Hydrogeochemistry

As mentioned above that groundwater exploitation via deep wells is concentrated on a confined aquifer system, then groundwater samples were taken from 58 deep wells. Hydrogeochemical characteristics of the confined aquifer were analysed for major cation~~s~~ (K^+, Ca^{2+}, and Mg^{2+}) and anion~~s~~ (SO_4^{2-}, Cl^-, and HCO_3^-) contents. Samples were chosen randomly in the study area and collected from unpublished reports (Mulyana and Wahid 1994; DGTL 2003; P.T. Gea Sakti 2006; Susana and Harnandi 2007). The correctness of the chemical analysis is verified by calculating the ion-balance error (IBE) using Eq. 1. It was found that the IBE of all samples were less than 10% as shown in Table 1, which ensured the reliability of the chemical data.

Table 1 The major ion~~s~~ content, of groundwater samples (Data source: Mulyana and Wahid, 1994; DGTL, 2003; P.T. Gea Sakti, 2006; Susana and Harnandi, 2007)

No.	Location	eC	Major ion~~s~~ content [meq L^{-1}]							IBE	Aquifer
		[µS cm^{-1}]	K^+	Ca^{2+}	Mg^{2+}	Na^+	SO_4^{2-}	Cl^-	HCO_3^-	[%]	Type
1	Obs. Pelabuhan	3,010	0.36	9.87	5.91	25.2	0.36	35.0	3.02	7.53	Qm
2	Obs. STM Perkapalan	1,447	0.36	1.47	3.35	13.0	0.40	9.49	8.52	-1.06	Qm
3	Obs. LIK Kaligawe	4,650	0.63	1.95	16.2	29.6	0.95	42.4	4.83	0.34	Qm
4	Obs. Unisula 2	23,900	0.43	36.5	149	313	0.84	444	37.1	3.55	Qm
5	Obs. Kec. Pedurungan	914	0.37	1.85	2.96	6.52	0.29	4.10	7.84	-4.38	Qm
6	Desa Gemolak	1,006	0.13	0.83	1.34	8.70	0.26	3.23	6.70	7.61	Qm
7	Obs. Standart Battery	363	0.17	2.69	1.21	1.57	0.13	1.23	4.24	0.57	Dm
8	Obs. Citra Land	226	0.29	0.71	0.49	1.35	0.66	0.73	1.29	6.19	Gr
9	Obs. PT. Kimia Farma	457	0.19	2.43	1.84	1.22	0.24	0.47	5.17	-3.39	Dm
10	Obs. Sumberejo	1,024	0.08	1.06	0.19	10.4	0.62	3.99	6.58	5.01	Qm
11	Aquaria	672	0.15	1.25	0.74	5.74	1.10	0.55	5.91	4.26	Gr
12	Obs. Katon Sari	3,580	1.11	18.9	6.82	20.0	1.35	27.9	14.7	6.43	Qm
13	Obs. Batu	1,762	0.24	1.09	2.77	13.0	0.76	7.05	8.52	4.90	Qm
14	Hotel Rahayu	1,902	0.23	7.08	1.30	27.0	0.46	28.3	3.96	8.49	Qm
15	Es Prawito Jaya Baru	370	0.17	2.43	1.10	1.13	0.20	0.59	4.00	0.90	Dm
16	Gudang PT Djarum	789	0.14	3.13	1.52	4.22	0.78	4.10	4.55	-4.56	Gr
17	SU Mangunharjo	626	0.24	0.54	0.35	5.00	0.35	3.59	2.49	-4.81	Qm
18	PT Sandratex	1,220	0.41	3.49	2.65	6.09	0.99	7.28	4.15	1.75	Qm
19	Bukit Perak	452	0.18	2.73	1.30	1.61	0.14	1.26	4.21	3.39	Dm
20	CP Prima	673	0.09	2.32	0.41	3.48	1.35	1.62	3.11	3.72	Gr
21	PT Sarana Mina	807	0.08	0.78	0.54	6.26	1.79	1.56	4.52	-2.65	Gr
22	Desa Bulusari	850	0.06	0.70	0.32	6.52	2.05	2.57	2.37	8.46	Qm
23	RRI Kuripan	911	0.26	1.85	0.74	6.43	1.66	1.31	5.94	4.09	Qm
24	Kartika sirup Gubug	584	0.22	1.45	0.57	4.35	0.25	1.38	5.11	-2.32	Qm
25	Obs PRPP	1,623	0.42	1.44	2.93	11.3	0.60	11.5	4.89	-5.68	Qm
26	Aorta, Kaligawe	636	0.09	1.02	0.12	5.57	1.18	1.16	4.52	-0.89	Gr
27	Bulusan Karangtengah	1,183	0.26	0.43	0.11	10.6	0.95	5.95	4.40	0.86	Qm
28	Desa Karangsari	631	0.04	0.24	0.50	5.57	1.32	1.56	2.92	9.02	Qm
29	Desa Trengguli	3,890	0.50	15.5	6.81	19.1	1.59	35.3	6.31	-3.05	Qm
30	Desa Rejosari	2,300	0.17	2.16	1.07	21.7	0.80	22.9	2.12	-2.55	Qm
31	PT. Ny.Meneer-1	704	0.17	0.50	0.49	5.22	1.93	1.01	3.64	-3.01	Gr
32	Obs. Indofood	349	0.15	2.12	1.47	1.17	0.45	0.32	3.91	5.27	Dm
33	Obs. Sampokong	671	0.64	0.61	0.04	4.30	0.46	1.12	3.85	2.90	Gr
34	PT. Panca Tunggal-1	2,370	1.25	3.25	2.20	18.6	0.97	21.4	4.24	-5.22	Qm
35	Hotel Oewa Asia	1,023	0.26	1.28	1.26	7.83	1.26	6.46	3.32	-3.92	Qm
36	PT. INAN	1,372	0.13	0.44	0.66	6.52	1.36	3.84	2.81	-3.47	Qm
37	Obs. SD Kuningan	759	0.26	0.19	2.39	6.43	1.49	1.05	6.21	5.62	Gr
38	PT. Sango Keramik	408	0.15	2.06	0.99	1.30	0.23	0.39	4.29	-8.57	Dm
39	Dolog Mangkang	557	0.23	2.25	1.35	2.17	0.80	1.61	3.80	-3.30	Dm
40	Hotel Santika	1,341	0.26	2.69	2.42	6.96	0.31	6.31	5.83	-1.11	Qm
41	PT Wahyu Utomo	373	0.15	2.31	1.12	2.17	1.47	0.35	4.40	-7.67	Dm
42	PT. Gentong Gotri	1,020	0.39	1.81	2.85	5.83	0.32	4.89	4.94	6.85	Qm
43	Tambakharjo, Tugu	2,790	0.47	0.53	4.94	13.9	0.46	18.7	1.92	-6.03	Qm
44	Tambak Udang, Mangkang	790	0.31	0.13	0.74	7.13	2.57	3.14	2.78	-2.31	Qm
45	PT. Damaitex	1,240	0.36	7.13	0.99	2.39	0.89	4.94	4.52	4.93	Qm
46	Desa Donorejo	1,650	0.06	0.96	0.64	12.0	3.39	5.00	6.07	-5.67	Qm
47	Guntur	1,350	0.24	0.88	0.44	10.8	3.46	2.81	6.27	-1.63	Qm
48	PDAM Manyaran	900	0.30	2.65	1.82	1.61	0.14	0.36	5.78	1.59	Dm
49	RS Kariadi	680	0.19	3.38	1.71	2.17	0.34	1.22	5.29	8.50	Dm
50	Hotel Metro Int	1,200	0.27	2.13	1.10	7.30	1.66	6.07	4.15	-9.40	Qm
51	Jamus Mranggen	800	0.16	0.88	0.44	5.65	0.75	0.77	5.27	4.97	Qm
52	PT Amor Abadi	690	0.20	0.41	0.26	6.09	1.39	1.02	4.27	4.06	Gr
53	Pabrik Kembang Gula Sano	685	0.20	1.40	0.99	5.87	1.11	0.59	7.61	-9.64	Gr
54	Hotel Siranda	740	0.19	4.50	1.94	2.70	0.37	1.97	6.20	8.86	Dm
55	Sendangguwo	694	0.19	3.40	1.73	2.22	0.34	1.15	5.34	9.66	Dm
56	Rowosari	1,259	0.20	0.90	1.73	6.96	0.44	0.70	7.75	9.57	Qm
57	Tandang	694	0.20	3.45	1.71	2.39	0.35	1.21	5.51	9.23	Dm
58	Ngalian	982	0.13	4.33	3.10	0.96	0.32	1.58	6.16	5.63	Dm

Furthermore, the major cation and anion contents were plotted in Piper diagram to determine the water type according to the Furtak and Langguth classification (1967), as shown in Fig. 3. It clearly depicts that the water type of Garang (Gr) is predominantly (hydrogen-)carbonate alkaline water while the Quaternary marine (Qm) contains predominantly chloride alkaline water, locally alkaline earth water type. The Damar (Dm) aquifer contains fresh water in volcanic rocks classified as predominantly hydrogencarbonate

How do you know? Reference? Data?

alkaline earth water with typically higher alkaline. Cation exchange processes occur when the water composition of Quaternary marine is often dominated by Ca^{2+} and HCO_3- flowing from intermediate towards lower slopes and plain. Sediments in these areas adsorb Ca^{2+} while Na^+ is released. Thus Garang aquifer has a $NaHCO_3$- water type. Meanwhile, groundwater along plain and coastal areas show dominant Na^+ and Cl^- ions due to intensive groundwater pumping for a long time that causes seawater to intrude into Qm.

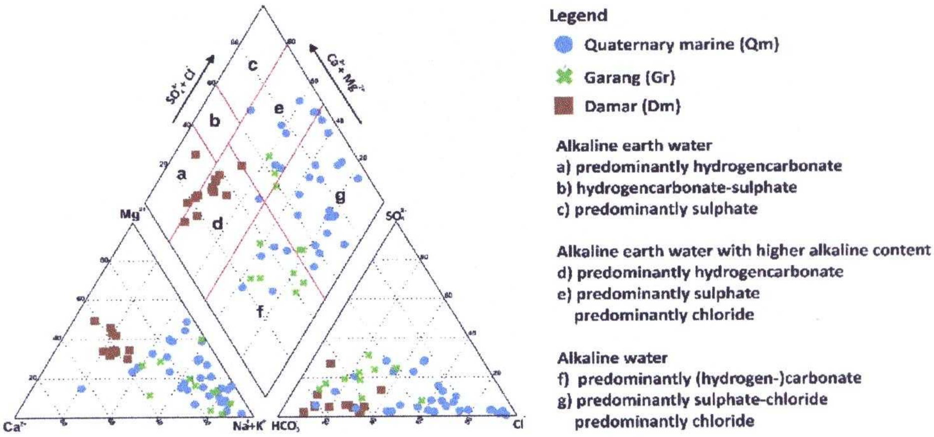

Fig. 3 Hydrogeochemistry classification of groundwater samples in a confined aquifer using piper plot.

→ this is water chemistry not basis for aquifer distribution.

Figure 4 shows lateral distribution of confined aquifer groups based on major cation and anion contents. As explained before, Gr and Qm have the same lithologic compositions, which are alluvium deposits, but they have different electrical conductivity (eC) values. Qm has higher eC value, which is > 807 μS cm^{-1}, than Gr as an impact of seawater intrusion due to overexploitation, as shown in Table 1. Qm dominantly spreads out in plain and coastal areas, while Gr in the centre of Semarang to the north east and forms a ridge below surface. While Dm spreads out in the hilly area towards intermediate slope.

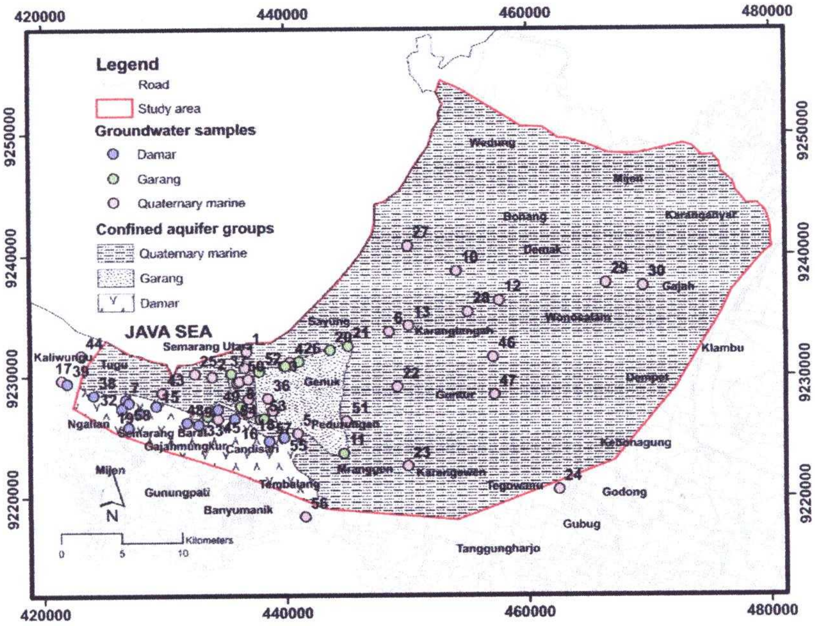

Fig. 4 The lateral distribution of confined aquifer groups

Hydrostratigraphical units (HSU)

It was extremely difficult to correlate stratigraphical details over any significant distance, because of lithologic heterogeneity in the study area. The lithologies are clay, clayey sand, tuffaceous sand, sand, conglomerate and sandy limestone, based on borelog data. The concept of HSU was applied to generalise the hydrogeological system in the study area (Fig. 5). There are two aquifers, three aquitards and one aquiclude in the study area. The description of HSU is discussed based on the hydrostratigraphical cross sections (Fig. 6). They refer a conceptual diagram of the volcanic sedimentary sequence in Central Java by Lloyd et al. (1985). The volcanic deposit and sedimentary derivatives considered the stages related to volcanic centre: the intermediate and lower slopes and the coastal plains as shown in the hydrogeological cross section.

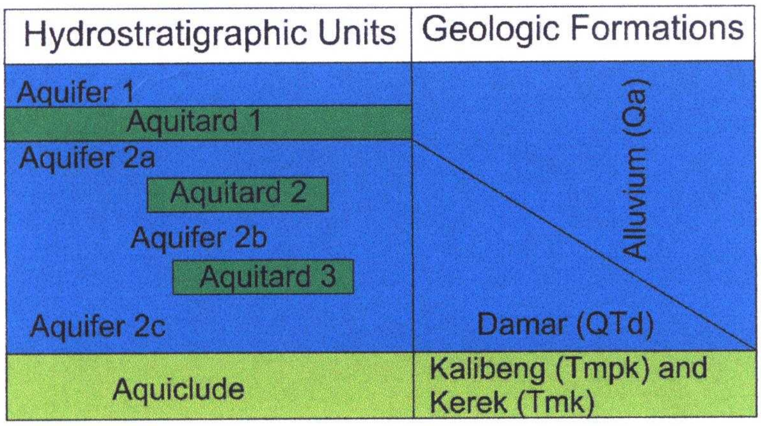

Fig. 5. Hydrostratigraphy units of the study area

From cross section A-B, the unconfined aquifer, which is Aquifer 1, spreads out from the intermediate slope to plains area. In plains area, It ~~unconfined aquifer~~ consists of loose deposits such as clayey sand and sand (alluvium deposit), while in the lower and middle slopes It consists of clayey sand, conglomerate, and sand (sedimentary and volcanic sediments). Groundwater head of the unconfined aquifer is controlled by morphological forms. Groundwater level is deeper in the southern part, in accordance with topographic expression which is higher in the south. From the cross section C-D, the topography is relatively flat (plains area) and groundwater head of unconfined aquifer is close~~d~~ to the surface.

The confined aquifers, Aquifers 2, consists of three groups which are, Garang (2a), Quaternary marine (2b) and Damar (2c) aquifers. Quaternary marine and Garang aquifers are surficial deposits (Qa) while Damar aquifer consists of sedimentary rocks (QTd).

The clay layer ~~both~~ in both cross sections (A-B and C-D) separates unconfined and confined aquifers, which forms an aquitard. There are 3 aquitards in the cross sections. Aquitard 1 is found in all areas varying from 5 to 30 m thick in the centre towards to the north, and becomes thinner to the south. Conversely, Aquitards 2 and 3 spread unevenly in the study area. They are inserted in ~~the~~ Aquifer 2 and varying in thickness around 5-20 m.

As an impact of intensive groundwater abstraction in the central ~~of~~ Semarang area, groundwater head of confined aquifer in cross section A-B is deeper than in the lowland area. ? In case of cross section C-D, groundwater head is close to the surface in the east. Groundwater flows from hilly area in the south towards the plain area in the north. Sandy limestone in the bottom of confined aquifer is an impermeable zone/aquiclude and acts as a basement in the hydrogeological system.

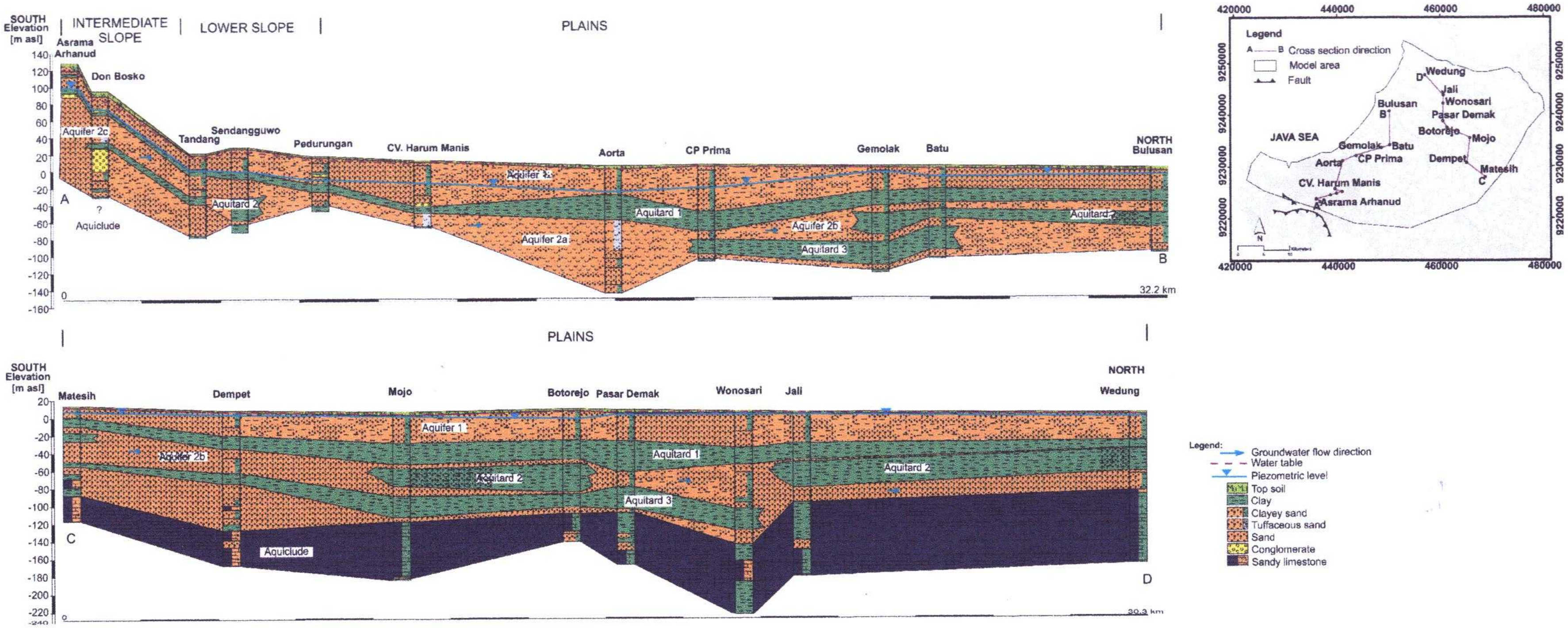

Fig. 6 Two hydrostratigraphical cross sections which show the aquifer system in the study area.

Conclusion and outlooks

The present study integrates geological and hydrogeological data to construct a hydrogeological model of aquifer system in Semarang. The ~~H~~hydrostratigraphical units of Semarang consist of two aquifers (Aquifer 1 and Aquifer 2), three aquitards and one aquiclude. Based on the hydrogeochemi~~stry~~cal analysis ~~from~~ of ion content, Aquifer 2 is separated into three groups which are Garang (aquifer 2a), Quaternary marine (aquifer 2b), and Damar (aquifer 2c).

not valid!

Moreover, applying this hydrogeological model into a numerical groundwater flow model will provide quantitative assessments to simulate groundwater level in respon~~d~~se to the future social and economic demands.

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